Preprint
UCRL-JC-145221

Shock Induced Birefringence in Lithium Fluoride

J. H. Nguyen, N. C. Holmes

This article was submitted to APS-SCCM, Atlanta, June 2001

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

June 1, 2001

SHOCK INDUCED BIREFRINGENCE IN LITHIUM FLUORIDE

Jeffrey H. Nguyen and Neil C. Holmes

Physics and Advanced Technology, Lawrence Livermore National Laboratory, Livermore CA 94551

Abstract. We have used an ellipsometer to measure the birefringence of lithium fluoride in shock compression experiments. In previous x-ray diffraction experiments, single crystal [100] LiF has been reported to remain cubic at moderate pressures.

INTRODUCTION

Lithium fluoride is a commonly used window in shock compression experiments. It has been reported to remain transparent at megabar pressures [1]. Since data are collected through the window, it is important that its optical properties are well characterized. In fact, its opacity and emission are some of the properties examined by various researchers [2]. For studies where polarization of light is measured, there is currently no data on its birefringence except at very low pressures [3-10].

Under stress of less than 1 kilobar, lithium fluoride exhibits birefringence [3-10]. Yet, under large shock compression along the [100] direction, LiF unit cell is compressed isotropically [11-14]. Shock along the [111] direction, however, yields uniaxial compression.

EXPERIMENTAL PROCEDURE

We have developed a miniaturized ellipsometer to look at the optical properties of the window under shock compression. Ellipsometry is well developed for thin film measurements as well as for emissivity studies [15]. The technique essentially measures the change in polarization of a reflected laser beam off a surface under study.

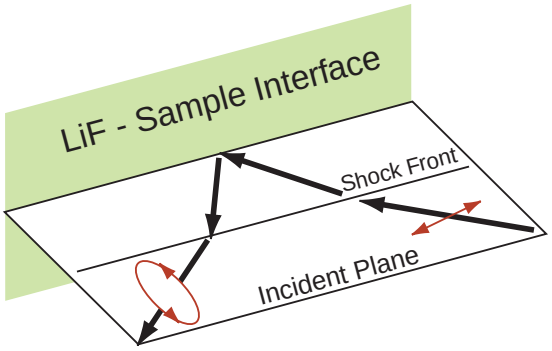

Figure 1. Path taken by the polarized light. Incident plane perpendicularly intersects the LiF-Sample interface. The shock front forms a boundary between the compressed and uncompressed sections of LiF window.

We used a LiF window in order to study the optical properties of the metal surface at high pressure. The window allows observations at the interface, and keeps the surface from releasing to ambient pressure. The target is made of an iron or aluminum disk and a [100] direction LiF window (see fig. 1). The window is coated with a 7000 Å layer of aluminum or iron, matching that of the disk. The LiF window is a circular disk with 25-mm diameter and 2 to 5 mm in thickness. We optimize the window thickness to allow sufficient time for observation and at the same time keep collecting optical fibers close to the metal-window interface.

Shock compression is a violent process for which sensitive optical measurements such as ellipsometry need a robust design. We accomplished that by enclosing the entire ellipsometer in a fiber bundle (fig. 2). The bundle is composed of seven optical fibers. One centrally located and the other six are arranged along the perimeter of the bundle. Polarizers cover the entrances of the six outer fibers. The polarizers are oriented at 30 degrees apart, covering a span from 0 to 150 degrees. The center fiber is left unpolarized. It is primarily used for intensity normalization.

As the shock front crosses the metal-window interface, it causes the interface to move and tilt slightly. This slight perturbation of the reflecting surface is sufficient to for a precise optical system to lose signal. We compensate by expanding the incoming 532 nm laser beam to cover the whole surface of the reflecting surface being shocked. The incoming and outgoing light typically enters or exits the window at roughly 45-degree angles.

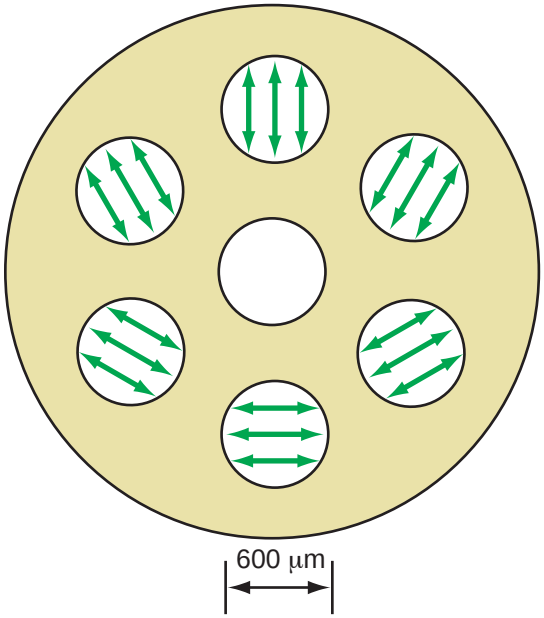

Figure 1. Front end of fiber bundle. Polarizers oriented at 30 degrees apart cover the six outer optical fibers. Central fiber is not polarized.

RESULTS

Propagation of the light through the air-LiF interface, LiF window, and reflection off the LiF-metal interface can be characterized a priori. As the shock front travels through the LiF window, two additional components become important to the light path: the shocked LiF window and the shocked and unshocked LiF-metal interface. Thicknesses of the LiF windows – both shocked and unshocked – change with the movement of the shock front, resulting in an optical system that changes with time. Moreover, the metal-window interface goes from an ambient pressure state abruptly to a high temperature and pressure state, forcing a change in the reflectivity of the polarized light. Polarization prior to shock compression can be described mathematically as

$$P = ARA.$$

Polarization is affected by the LiF window, A, and the metal-window interface, R. We have ignored the air-LiF window interface in our calculation since it does not change during the relevant duration of the experiment.

As the shock front travels through the window, mathematical representation of the polarization state becomes

$$P(t) = A(t)IA'(t)R'[\theta(t)]A'(t)IA(t).$$

The polarization state is affected by the distance it has to travel through the shocked and unshocked windows, A'(t) and A(t). Reflectivity at the metal-window changes abruptly as it undergoes compression. As the polarization of the light arriving at the interface changes as it travels through the windows, reflectivity at the interface changes with the polarization state R'[θ(t)].

Change in thickness of the windows result in a sinusoidal change in the polarization due to stress-induced birefringence in the window. However, a change in the reflectivity of the sample-window interface due to changing polarization is more complex.

DISCUSSION

Prior to the introduction of the shock wave at the interface and window, the output has become elliptically polarized since the light traverses the window and reflects off the interface. Polarization, and thus ellipticity, remains constant prior to the arrival of the shock front. After being shocked, the interface remains at a shocked steady state. Changes in the optical properties at the interface thus result in a discontinuous change in the polarization data. Optical properties of the shocked LiF window are only observed after the shock front enters the window.

In figure 3, we present light intensity vs. time at various polarization angles. The fibers measure output light at fixed polarization angles. As the distance the light has to travel through the sections of the window changes linearly with time, differences in thickness of the window sections contribute to the changes in the polarization, which manifest itself as the rotation of polarization.

As polarization changes with the growth of the shocked region of the window, the reflectivity of the metal-window interface changes with the state of polarization of the incoming light source. This results in a non-sinusoidal change in the output intensity. We note that if the shocked window material is isotropic in its optical character, i. e. no birefringence, the polarization in the window remains constant in time.

We performed an additional experiment to positively identify the source of the sinusoidal changes in the output signal. We replaced LiF with water as the window material. Water is transparent to visible light at pressures up to 25 GPa. Since it remains in the liquid phase for the duration of the experiment, shear strength is essentially nonexistent. Water at high pressure is thus not expected to change polarization of light traversing the window.

In figure 4, we present data taken with water as a window. At similar pressure and temperature, data taken with water exhibit no sinusoidal property. The data show changes at the water-sample interface as expected. The results clearly indicate that LiF is responsible for the sinusoidal change in polarization of the light beam.

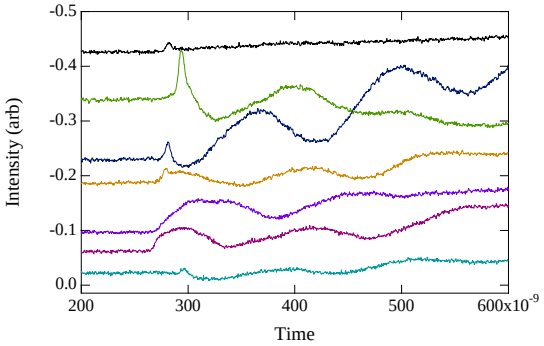

Figure 3. LiF window. Output of polarized light recorded at various pressures. The top line is from the output of the unpolarized optical fiber.

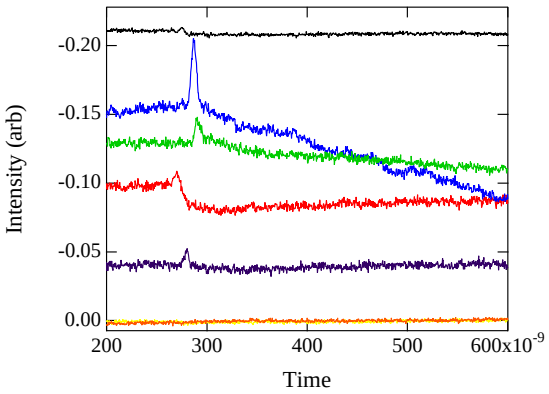

Figure 4. Water window. Output of polarized light recorded at various pressures. The top line is from the output of the unpolarized optical fiber.

ACKNOWLEDGMENTS

We gratefully acknowledge the invaluable technical support provided by Samuel B. Weaver, William J. Metz, Jr., Steven J. Caldwell, James G. Van Lewen, Erikk A. Ojala and Jeff van Lue. We also benefited greatly from discussions with Dr. Dave Hare.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Lab under contract No. W-7405-ENG-48

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